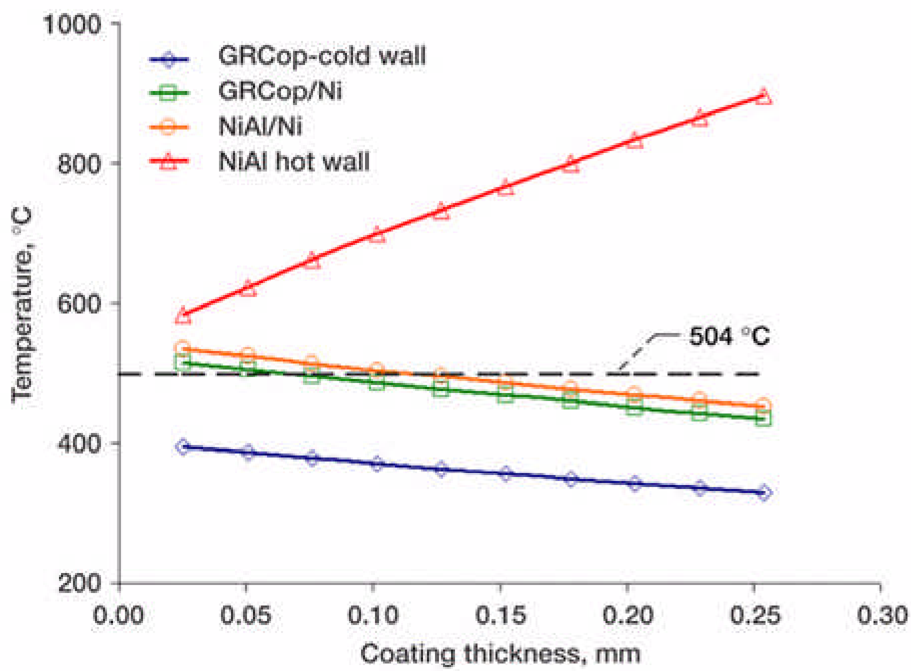
NiAl Coatings Investigated for Use in Reusable Launch Vehicles

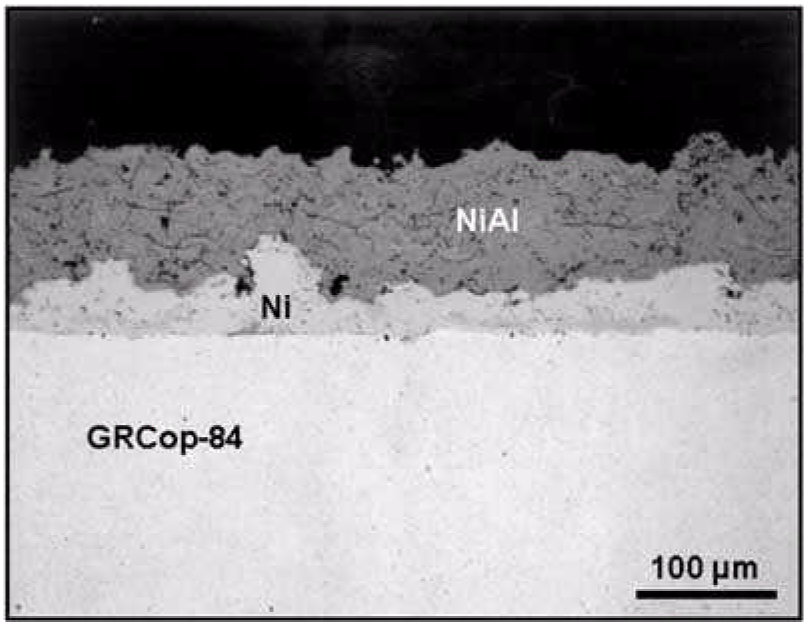
As part of its major investment in the area of advanced space transportation, NASA is developing new technologies for use in the second- and third-generation designs of reusable launch vehicles. Among the prototype rocket engines being considered for these launch vehicles are those designed to use liquid hydrogen as the fuel and liquid oxygen as the oxidizer. Advanced copper alloys, such as copper-chromium-niobium (Cu-8(at.%)Cr-4(at.%)Nb, also referred to as GRCop-84), which was invented at the NASA Glenn Research Center, are being considered for use as liner materials in the combustion chambers and nozzle ramps of these engines. However, previous experience has shown that, in rocket engines using liquid hydrogen and liquid oxygen, copper alloys are subject to a process called blanching, where the material undergoes environmental attack under the action of the combustion gases. In addition, the copper alloy liners undergo thermomechanical fatigue, which often results in an initially square cooling channel deforming into a dog-house shape. Clearly, there is an urgent need to develop new coatings to protect copper liners from environmental attack inside rocket chambers and to lower the temperature of the liners to reduce the probability of deformation and failure by thermomechanical fatigue.



Effect of NiAl coating thickness on the expected temperature distribution of the GRCop-84 substrate in a rocket engine. Temperature of the hot gas, 3277 °C; coolant temperature, -176 °C; convective heat transfer coefficient of the hot gas, 12 363 $W/m^2/K$; convective heat transfer coefficient of the coolant, 58 283 $W/m^2/K$.

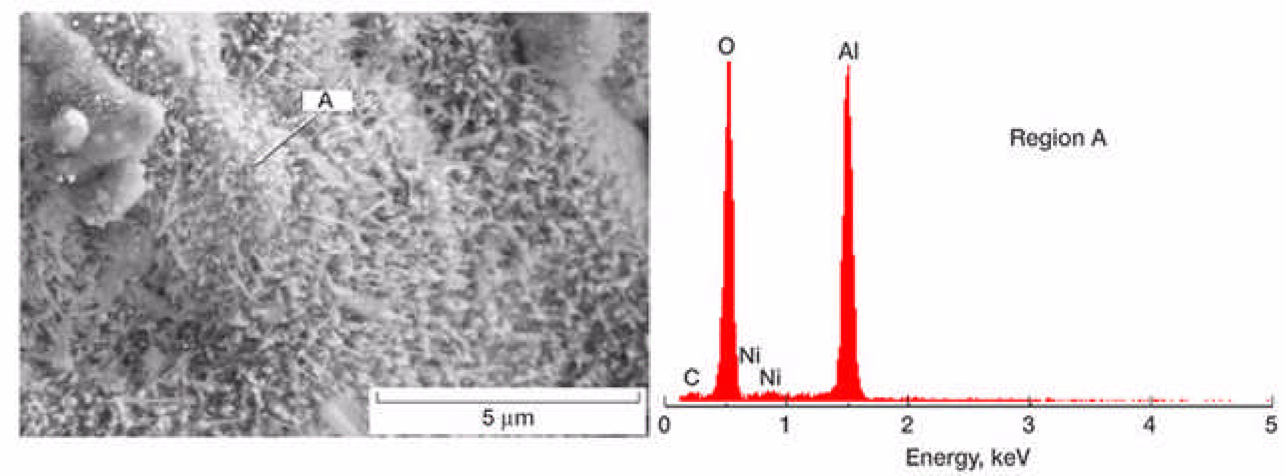
Glenn is actively developing and characterizing several advanced protective coatings for

GRCop-84 liners and nozzle ramps for reusable launch vehicle applications. Nickel aluminide (NiAl), which has been extensively investigated at Glenn for aircraft engine applications, was chosen as a coating in this study because of its mechanical and oxidation properties. It is well established that NiAl possesses excellent oxidation properties, has a lower density than GRCop-84, and a higher thermal conductivity than NiCrAlY. These desirable characteristics make it a logical choice as a candidate for study. Thermal modeling also suggests that NiAl can remain effective under the high-heat-flux conditions characteristic of a rocket engine combustion chamber (see the preceding graph). These calculations indicate that the applied coating thickness should exceed 0.1 mm to ensure that the substrate temperature stays below 500 °C.

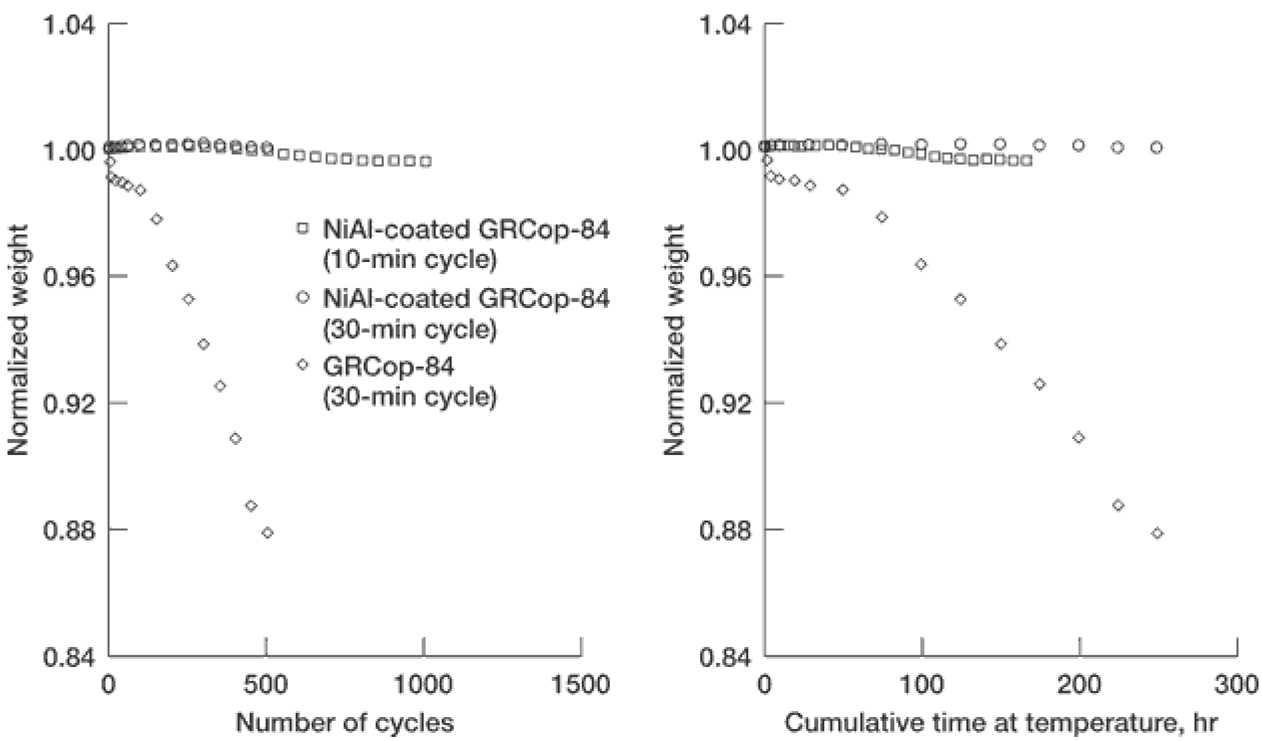


As-sprayed NiAl/Ni/GRCop-84.

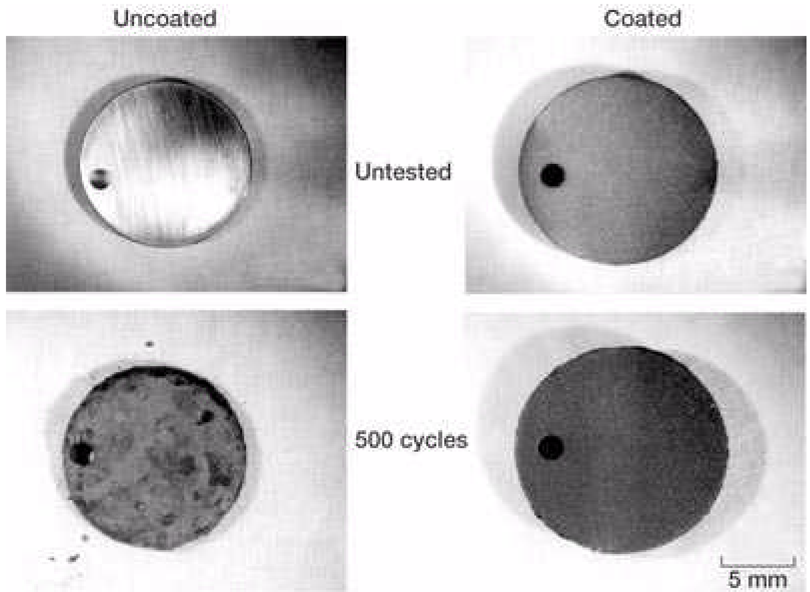
The preceding photomicrograph shows the cross section of a GRCop-84 substrate coated with a NiAl outer coating and a Ni bond coat by the low-pressure plasma-spraying process. The stability of the coating in hydrogen was tested by exposing coated specimens to flowing gas at 900 °C for various times up to 50 hr. Microstructural and chemical analysis of the coated surfaces revealed that the coating did not form nickel hydride and that only a stable protective alumina layer was observed (see the next photomicrograph). The effectiveness of the coating in protecting the substrate in an oxidizing environment was tested by thermally cycling disk specimens, coated on both faces, in air at 600 °C. Each cycle consisted of exposing the specimen to temperature for either 10 or 30 min followed by cooling to ambient temperature in 5 min. Periodic weight change and microstructural observations were made during the course of the tests and compared with similar observations of uncoated substrates. The following graphs confirm that the NiAl coating can protect the substrate from the oxidation effects of air as evidenced by the negligible change in weight for a proposed 30-min third-generation mission cycle (500 cycles, i.e., 250 hr) and for a planned 10-min second-generation mission cycle (100 cycles, i.e., 16.7 hr) before engine overhaul. In fact, the NiAl-coated substrate exceeded the proposed 100 mission cycles by a factor of 10. In contrast, the uncoated material lost about 13 percent of its original weight after 500 cycles. Microstructural observations of the surfaces of the coated and uncoated specimens before and after 500 cycles revealed that uncoated GRCop-84 oxidized and spalled profusely during the course of the test, thereby resulting in a significant weight loss (see the final photographs). In comparison, the surfaces of the coated substrate were crack free and intact. Further studies are underway to optimize the plasma spraying conditions and demonstrate the stability of the coatings in a high-heat-flux environment.



Microstructure and chemical analysis of the NiAl coating after annealing in pure hydrogen at 900 °C for 50 hr.



Thermal cycling behavior of coated and uncoated GRCop-84 at 600 °C.



Macrographs of coated and uncoated GRCop-84 thermally cycled at 600 °C.

Find out more about the research of the Environmental Durability Branch http://www.grc.nasa.gov/WWW/EDB/.

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